

Understanding the Impacts of Hydrologic Uncertainties on Floodplain Management Using Geographical Information Systems (GIS) Technology

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GENERAL

The development of the hydrologic and hydraulic data used in Floodplain Management Studies, Flood Insurance Studies, and other similar flood studies can greatly impact the end results of those analyses, i.e. the floodplain and structures affected by that floodplain. The very nature of the hydrologic and hydraulic analyses lends themselves to uncertainties in the calculated answers. Those uncertainties are the product of the data going into the analyses, the study methodologies, and the basic assumptions and experience of the study engineer. This paper documents a simple study of how the hydrologic and hydraulic uncertainties impact the results of floodplain development at one particular location.

BASIN AND FLOODPLAIN USED IN THIS ANALYSES

This study is a marriage of convenience. The floodplain analysis is based on backwater studies conducted for the Stillwater Creek Reconnaissance Study performed in late 1999. However, because no stream gage is present on Stillwater Creek, the hydrologic analyses performed are actually for the Council Creek basin located about 6 miles to the east of the Stillwater Creek floodplain. This paper presupposes that, for purposes of illustration only, the flows developed for the Council Creek watershed can be used for the backwater analyses on Stillwater Creek. The results are for comparison purposes only. Figures 1 and 2 show the location of the Council Creek watershed and the Stillwater Creek floodplain. The Stillwater Creek floodplain is located in north-central Oklahoma near the city of Stillwater, Oklahoma. The total drainage area of the Stillwater Creek basin is about 282 square miles. However, in 1937, the Soil Conservation Service, USDA, constructed the Lake Carl Blackwell dam, located about 6 miles west of the city of Stillwater. The drainage area upstream of the dam is about 75.4 square miles.

The Council Creek stream gage (ID 07163000) is located at mile 10.0 and drains an area of about 31 square miles. The period of record for the gage analysis was from 1934 through 1993. The vast majority of the Council Creek watershed is rural in nature, with rolling pastures and wooded areas.

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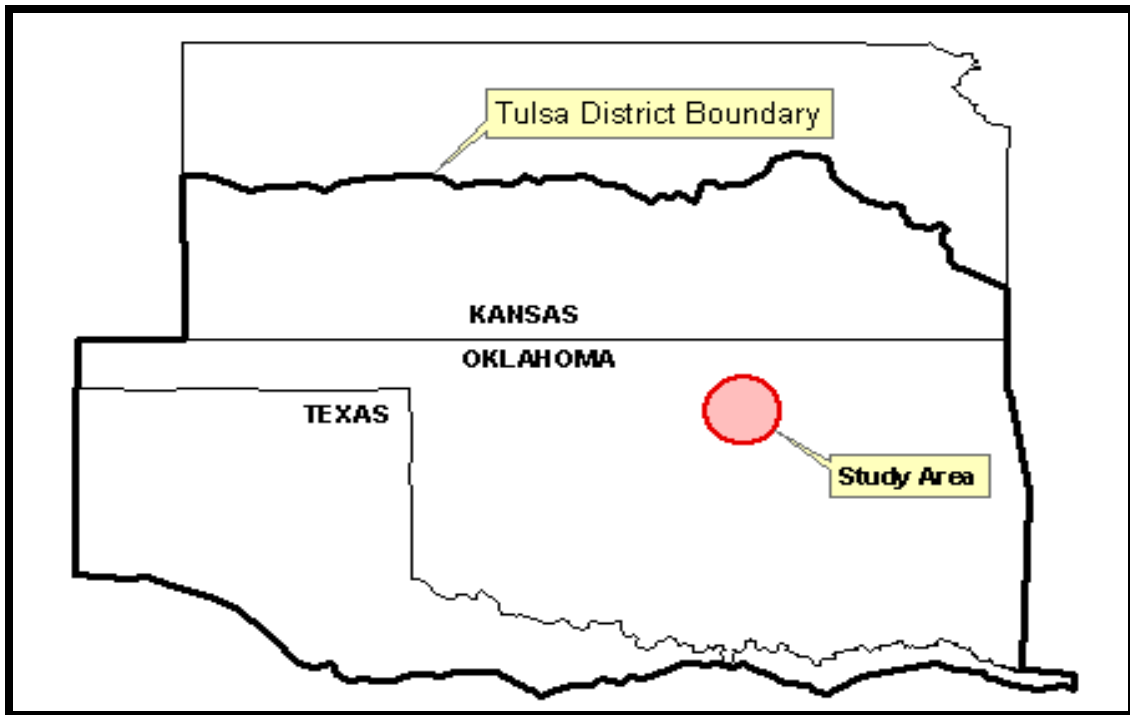


Figure 1 General Vicinity Map

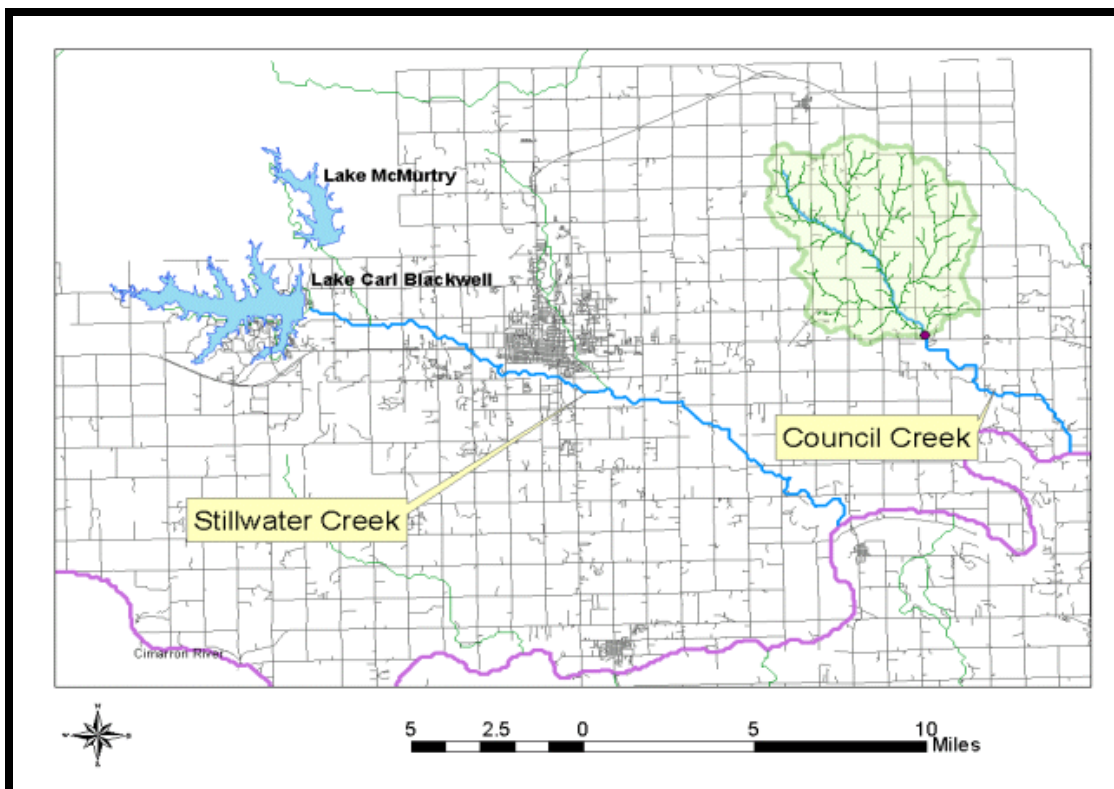


Figure 2 Stillwater Creek and Council Creek Locations

HYDROLOGIC ANALYSES

The basic final product of the hydrologic analyses is frequency flows developed for specific locations. Those flows are then used in the hydraulic (backwater) analyses to determine the flooding elevations and floodplain extents along the watercourse being studied. There are several methods that can be used to develop those frequency flows. The type of method selected in an individual study is dependent on the type and accuracy of hydrologic and watershed information available, monetary and policy constraints of the study itself, and the experience of the study engineer. For typical floodplain studies, the Tulsa District COE will usually use one of the following hydrologic study methods: stream gage frequency analyses, computer modeling of the basin and the rainfall – runoff process, or regional regression equations.

Stream Gage Frequency Analyses

Items that can cause uncertainties in the calculations resulting from a stream gage frequency analysis are: (1) length of the period of record for the stream gage, (2) selection of skew and mean square error, (3) treatment of high and low historic outliers, and (4) changes that might have occurred in the basin (i.e. construction of upstream reservoirs or intense basin development) creating an effective “mixed” period of record.

The discharge frequency analysis used in this study follows the guidance given in “Statistical Methods in Hydrology” and Bulletin 17b, “Guidelines for Determining Flood Flow Frequency”. A standard log-Pearson Type III discharge frequency analysis was used for the calculation of the frequency flows and statistics. Peak annual flows at the Council Creek near Stillwater stream gage vary from 247 cubic feet per second (cfs) to 25,000 cfs. Confidence limits of 25% and 75% were also calculated. Figure 3 is a chart showing the range of peak annual flows for the entire period of record.

A Mean Square Error value of .325 and a skew value of 0.0 were used for all log-Pearson Type III analyses. To illustrate the effects of the period of record has on the resulting frequency curves and statistics, four different scenarios were evaluated: (1) Entire period of record (1934 – 1993), (2) the first 30 years of record (1934 – 1963), (3) the last 30 years of record (1964 – 1993), and (4) the middle 40 years of record (1944 – 1983). Figures 4 through 7 illustrate those scenarios for the different periods of record.

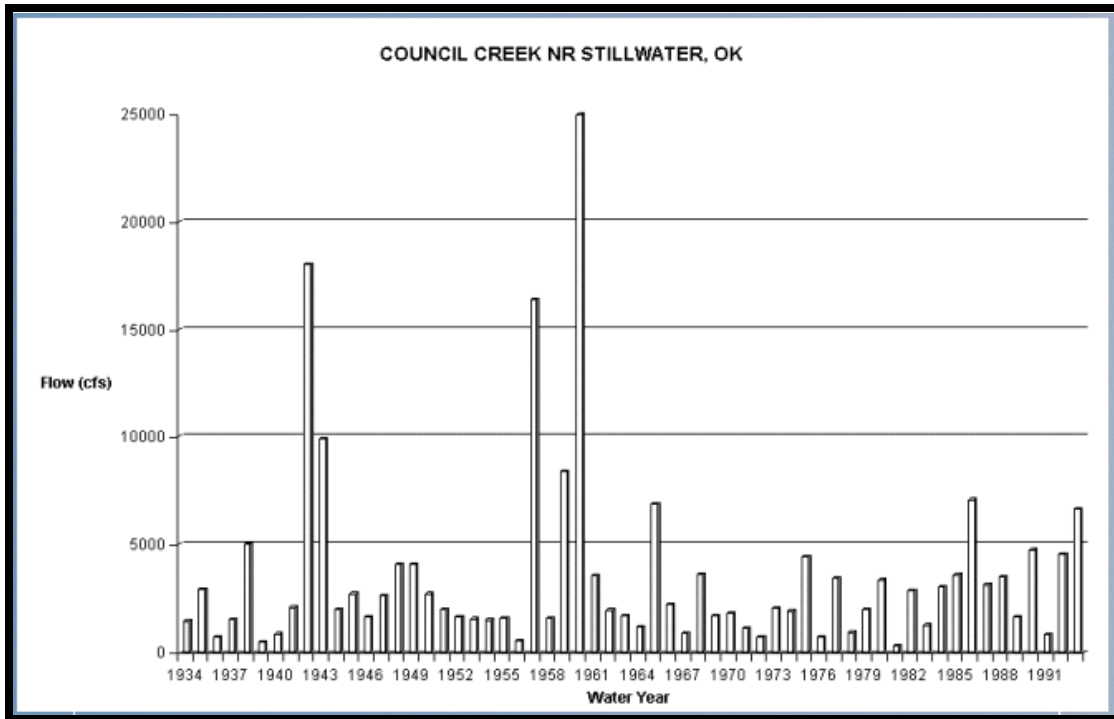


Figure 3 Council Creek nr Stillwater, OK Entire period of record

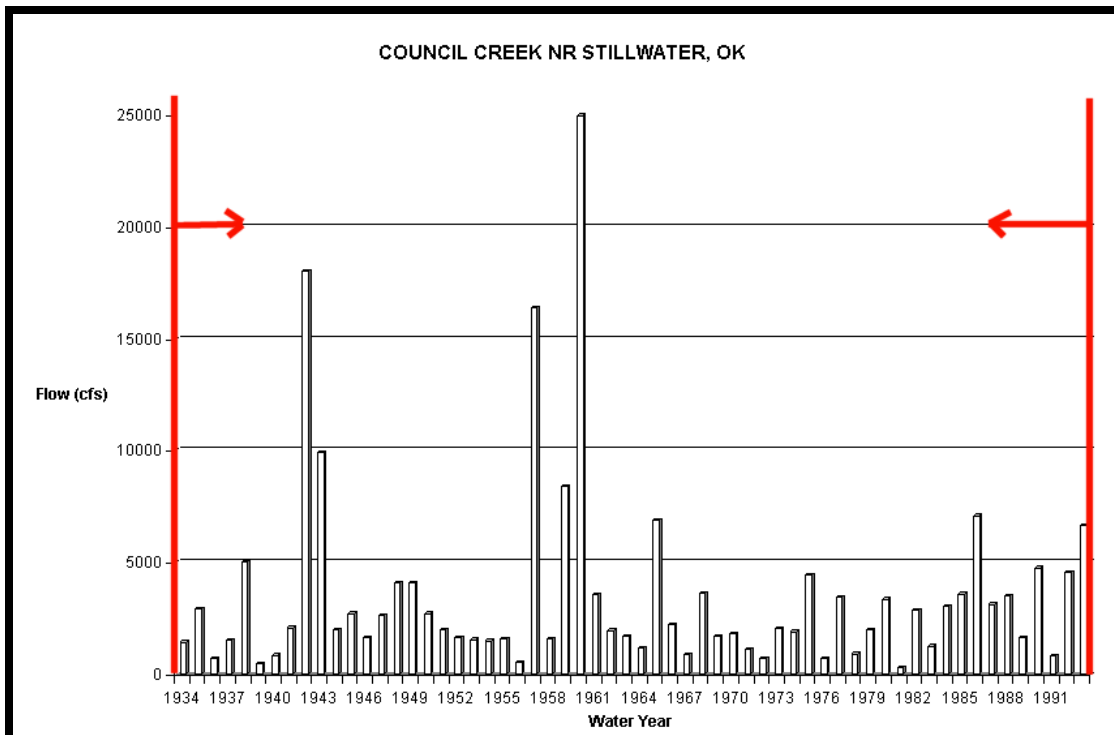


Figure 4 Period of Record 1934 - 1993

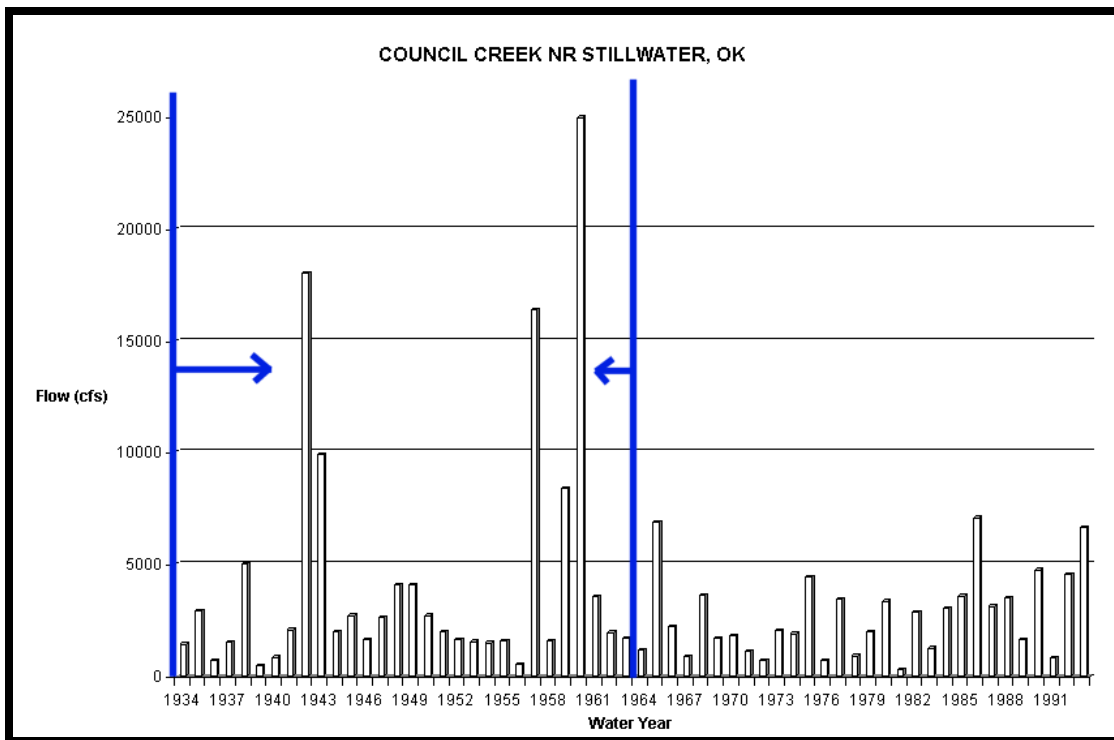


Figure 5 Period of Record 1934 - 1963

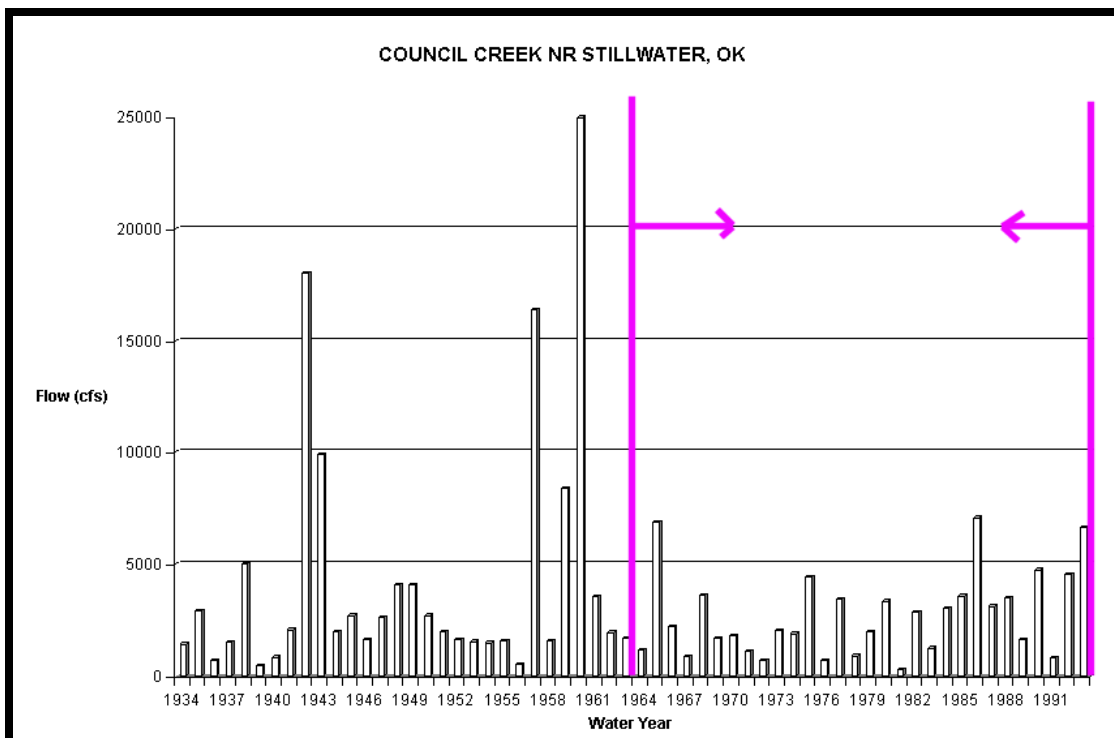


Figure 6 Period of Record 1964 - 1993

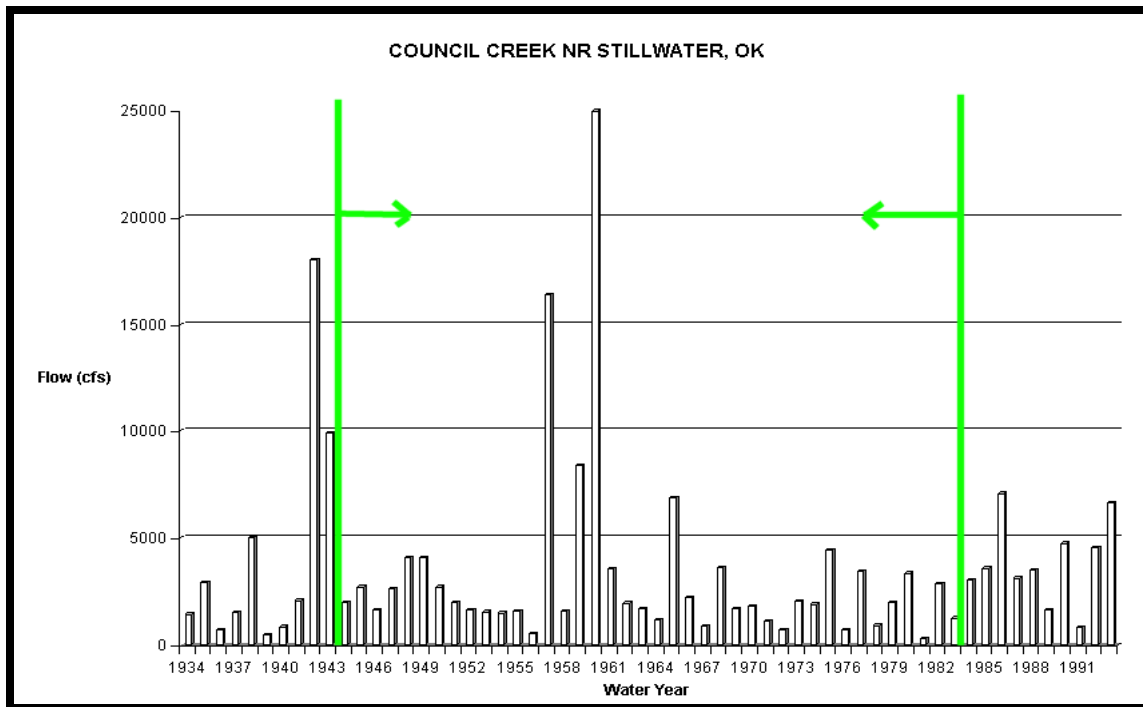


Figure 7 Period of Record 1944 - 1983

As is illustrated in Figure 8, significantly varying frequency curves and confidence limits resulted from the four different periods of records analyzed for the Council Creek near Stillwater stream gage. The 1% (100-year) frequency flood discharge varies from about 10,700 cfs to about 32,600 cfs, depending on which period of record one uses. Additionally, using the confidence limits as criteria for selection, that range would vary from 9,160 cfs to 43,100 cfs. The frequency analysis using the entire 60 years of record yields a 1% frequency flood of 20,700 cfs. Thus, it is very apparent that the availability and selection of data for the period of record can significantly impact the resultant flow calculations.

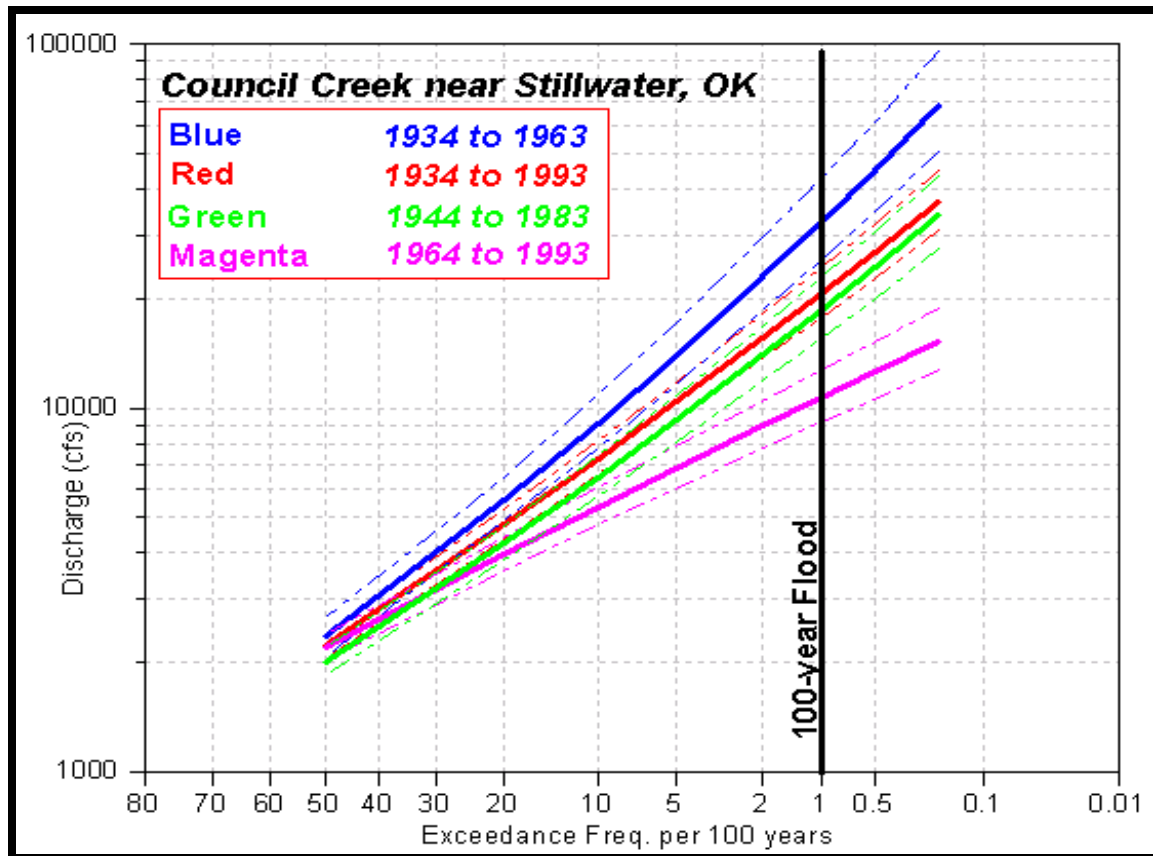


Figure 8 Discharge Frequency Curves, Stream Gage Analyses

Computer Modeling of the Rainfall-Runoff Process

Items that can cause uncertainties in the calculations resulting from a computer modeling of the rainfall-runoff process are: (1) Level of detail in the watershed's topography, (2) availability and period of record of nearby gaged basins for comparative studies, (3) availability of previous studies of similar watersheds in or near the local region, (4) assumptions for hydrologic parameters such as rainfall loss rates and basin development, and (5) methodologies and computer programs used in the modeling process.

The Council Creek watershed above the established stream gage was modeled using the COE Waterways Experiment Stations' computer program "**WMS - WATERSHED MODELING SYSTEM**", version 6.1, compile date June 1, 2002. The program incorporates Geospatial Data & Systems (GD&S) technology with the hydrologic runoff modeling capability of the Hydrologic Engineering Centers' computer program "**HEC-1 - FLOOD HYDROGRAPH PACKAGE**", version 4.0, dated September 1990. The WMS program will automatically determine the basin boundaries, slope, flow paths, basin area, and other pertinent parameters above a user selected outlet point. The following items were investigated to examine their relative impacts on the calculated 1% chance (100-year) flow at the Council Creek stream gage location: (1) topography detail, (2) selected loss rates, and (3) computation time interval.

Snyder's unit hydrograph coefficients were developed for each basin using the Tulsa

District (rural) parameter contained in the WMS program. Those relationships were developed from numerous studies within the District. Snyder's unit hydrograph concept relates streambed slope, stream length, and subarea shape to hydrograph peaking time, and is illustrated by the curves shown in Figures 6 and 7. Snyder's T_p and C_p were used in the hydrologic models to compute unit hydrographs for each basin. Total rainfall depths and temporal distribution were developed using data contained in the National Weather Service's Technical Paper No. 40 (TP-40) and Hydrometeorological Report No. 35 (HMR-35). Watershed topography was derived from 2 sources; the US Geological Survey (USGS) 7.5 minute series Digital Elevation Models (DEM) (NAD83) and the USGS 1:250,000 scale DEM (NAD27). Tables 1 and 2 show the hydrologic parameters developed for the different DEMs, loss rates, and computation intervals.

TABLE 1
WATERSHED HYDROLOGIC PARAMETERS

	7.5 Minute USGS DEM	1:250k scale USGS DEM
Grid Size (meter)	30	100
Calculated Basin Area (sq.mi.)	30.12	30.67
Basin Slope (ft./ft.)	0.0373	0.0121
Flow Length (feet)	49,670	48,875
Length to Centroid (feet)	22,627	19,128
Flow Length slope (ft./ft.)	.004899	.004281
Calculated Snyder's T_p	3.40	3.04
Calculated Snyder's C_p	.70	.65

TABLE 2
CALCULATED FLOWS FOR 1% CHANCE (100-YEAR) FLOOD

	7.5 Minute USGS DEM	1:250k scale USGS DEM
Losses = 0.0"initial, .02" constant Computation Interval = 30 min.	19,717 cfs	19,768 cfs
Losses = 0.0"initial, .02" constant Computation Interval = 60 min.	19,458	19,190
Losses = 1.0"initial, .02" constant Computation Interval = 30 min.	19,519	19,528
Losses = 1.0"initial, .02" constant Computation Interval = 60 min.	19,310	19,049
Losses = 2.0"initial, .04" constant Computation Interval = 30 min.	17,441	17,318
Losses = 2.0"initial, .04" constant Computation Interval = 60 min.	17,397	17,086

Figure 9 shows the highest and lowest 1% chance (100-year) flows calculated using the hydrologic computer model overlaid with the frequency curves previously shown.

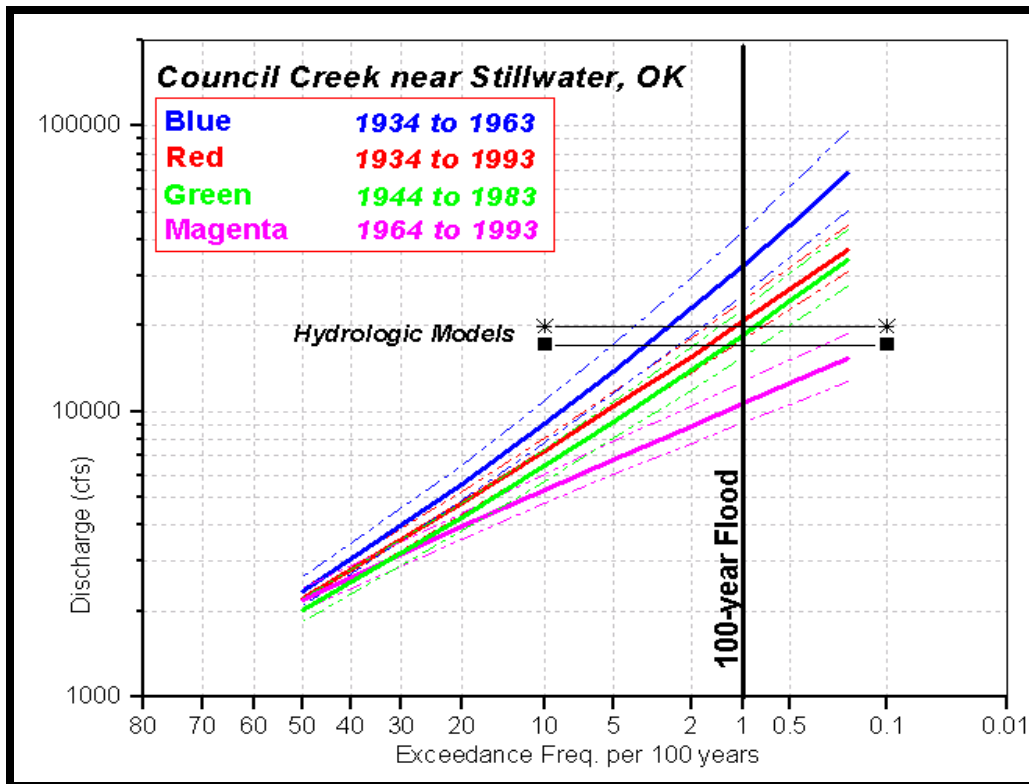


Figure 9 Hydrologic Modeling Results

Regression Equation(s) Analyses

Items that can cause uncertainties in the calculations resulting from the use of regressions are: (1) Estimation of the watershed slope, (2) estimation of mean annual rainfall, and (3) general inaccuracies of the regression equations due to the “lumping” of several gages to represent one particular gage. Three different publications were used to calculate the 1% chance (100-year frequency) peak flood flow at the Council Creek stream gage location. Those publications are: “Techniques For Estimating Flood Discharges For Oklahoma Streams” published in 1977, “Techniques for Estimating Flood Peak Discharges for Unregulated Streams and Streams Regulated by Small Floodwater Retarding Structures in Oklahoma” published in 1984, and “Techniques for Estimating Peak Stream flow Frequency for Unregulated Streams and Streams Regulated by Small Floodwater Retarding Structures in Oklahoma”, published in 1997. The equations used are as follows:

From the 1977 report -- $Q_{100} = 38.6(D.A.^{0.7})(S^{0.32})(P^{0.67})$

Where D.A. is Drainage Area in square miles, S is slope of the basin in feet per mile, and P is mean annual precipitation in inches.

So $Q_{100} = 38.6(30.12^{0.7})(25.86^{0.32})(32.6^{0.67}) = \mathbf{12,237}$ cfs

From the 1984 report -- $Q_{100} = 196(D.A.^{0.56})(P^{0.68})$

So $Q_{100} = 196(30.12^{0.56})(32.6^{0.68}) = \mathbf{14,106}$ cfs

From the 1997 report -- $Q_{100} = 35.6(D.A.^{0.614})(S^{0.202})(P^{0.907})$

So $Q_{100} = 35.6(30.12^{0.614})(25.86^{0.202})(32.6^{0.907}) = \mathbf{13,101}$ cfs

Figure 10 shows the results from the above calculations overlaid with the frequency curves and computer model results previously shown.

BACKWATER ANALYSES

Hydraulic backwater computations were performed using the computer program RiverCADD2000, from BOSS, INTL. That program incorporates the use of geospatial technologies with standard backwater computation procedures. The RiverCADD2000 program allows the user to import standard USGS Digital Elevation Models (DEMs) for the stream and floodplain geometry and facilitates the creation of the cross-section alignments and stream/overbank reach lengths. The program then uses the standard backwater calculations found in either HEC-2 or HEC-HMS to determine the frequency flood profiles along the watercourse. Once the calculations have been made, the user can then have the program automatically create and export the frequency floodplains into standard shapefile formats for subsequent plotting in the GIS program.

GEOGRAPHICAL INFORMATION SYSTEMS (GIS) ANALYSES

Geospatial technologies were used to aid in the quick analysis of the impacts that changes in the 100-year frequency flows had on the size of the floodplain and on the number of structures flooded. The GIS program used was ESRI's ArcView 3.2a.

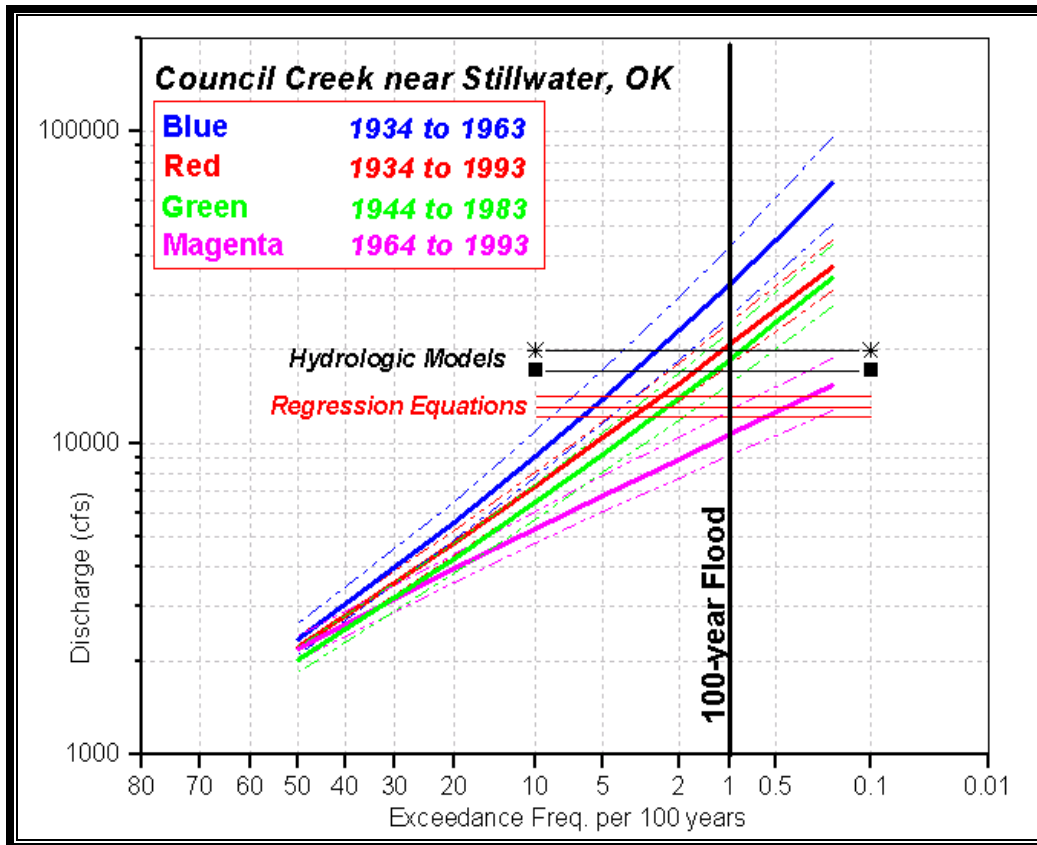


Figure 10 Regression Equations Results

The GIS allowed quick analysis of the different floodplain sizes and the number of structures impacted. To determine which structures would be affected, a “point” shapefile was created that assigned a “x-y” point for each structure. Due to the cursory nature of the original study, no distinction was made between structure types. Figure 11 illustrates the concept of using a single point for each structure.

Figures 12 and 13 show the floodplains created in the backwater computations for the various scenarios studied in the stream gage analyses.

From the two previous figures it is apparent that a change in the discharge frequency flow selected for the backwater computations can make a significant difference in the number of structures that would be shown as flooded. Figure 14 shows a table detailing the number of structures impacted by the different floodplains.

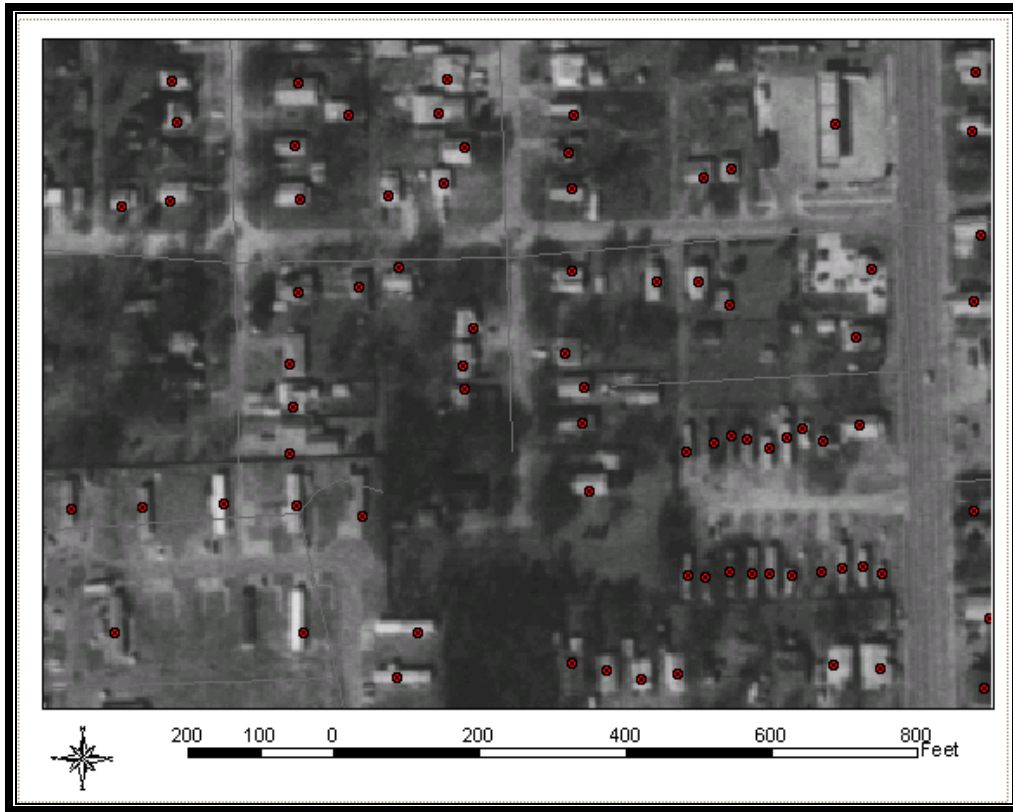


Figure 11 Using "Point" Shapefile for Structure Desingation

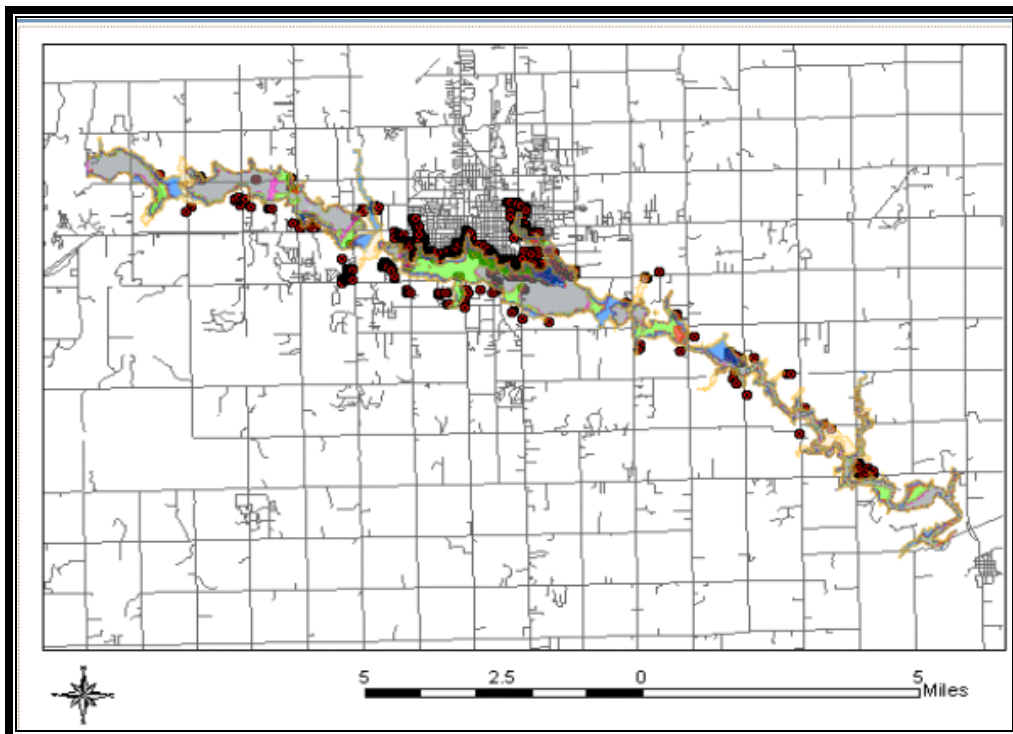


Figure 12 Calculated Floodplains for Stream Gage Analyses

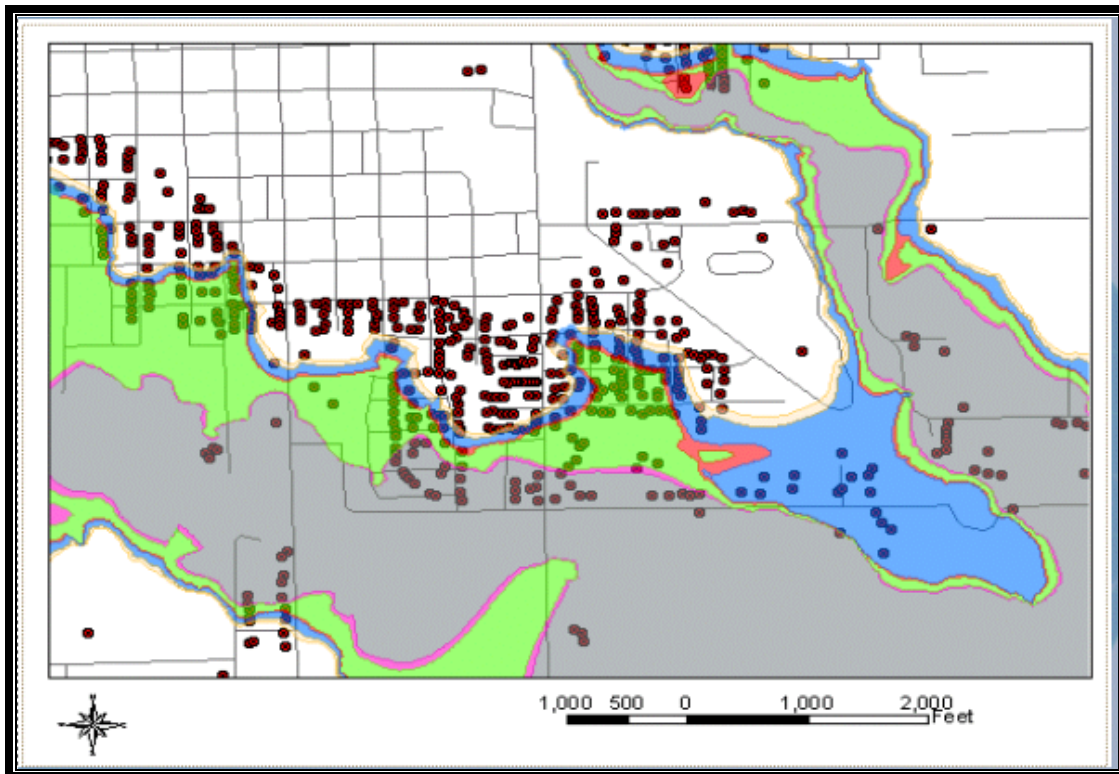


Figure 13 Calculated Floodplains for Stream Gage Analyses (Close-Up)

TABLE OF FLOODED STRUCTURES CHANGES IN DISCHARGE ONLY				
PERIOD OF ANALYSIS	FLOW (cfs)	COLOR	NO. OF STRUCTURES FLOODED	TOTAL VALUE OF STRUCTURES*
1934 - 1963 (25% conf. limits)	43,100	Beige	468	\$ 18,720,000
1934 - 1963 (calc. flows)	32,600	Blue	405	\$ 16,200,000
1934 - 1993 (calc. flows)	20,700	Red	282	\$ 11,280,000
1944 - 1983 (calc. flows)	18,600	Green	263	\$ 10,480,000
1964 - 1993 (calc. flows)	10,700	Magenta	107	\$ 4,280,000
1964 - 1993 (75% conf. limits)	9,160	Gray	103	\$ 4,120,000

*Assumes Average Structure Value of \$ 40,000

Figure 14 Table of Flows and Structures Flooded

Summary

It is evident from the information previously presented that hydrologic uncertainties play a significant role in the determination of frequency flows used in floodplain analyses and thus can play a significant role in the floodplain administrators' professional efforts. The current use of risk and uncertainty principles in the US Army Corps of Engineers provides an integral part in evaluating the projects' effectiveness, and this practice would benefit other Federal and State agencies performing hydrologic and hydraulic studies.

References

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